

AD-A184 257

THE IMPACT OF VAVES ON SOLAR PHYSICS(U) STANFORD UNIV
CA CENTER FOR SPACE SCIENCE AND ASTROPHYSICS
R N BRACEWELL MAY 87 CSSA-ASTRO-87-9 N00014-85-K-0111

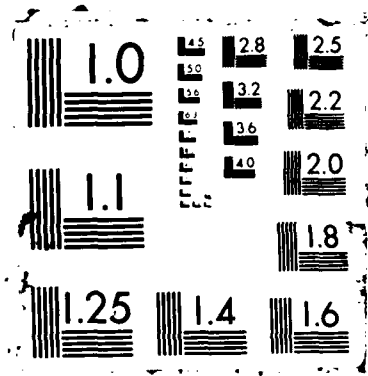
1/1

UNCLASSIFIED

F/G 8/8

NL

END
9-87
DTIC



(12)

DTIC FILE COPY

C S S A

AD-A184 257

THE IMPACT OF VARVES ON SOLAR PHYSICS

R.N. Bracewell

CSSA-ASTRO-87-9
May 1987

(to appear in Solar Physics)



DTIC
ELECTE
SEP 02 1987
S D

CENTER FOR SPACE SCIENCE AND ASTROPHYSICS
STANFORD UNIVERSITY
Stanford, California

DISTRIBUTION STATEMENT A
Approved for public release
Distribution Unlimited

87 8 14 051
87 8 14 051

THE IMPACT OF VARVES ON SOLAR PHYSICS

R.N. Bracewell

CSSA-ASTRO-87-9

May 1987

(to appear in Solar Physics)

Accession For	
NTIS CRA&I	<input checked="" type="checkbox"/>
DTIC TAB	<input type="checkbox"/>
Unannounced	<input type="checkbox"/>
Justification	
By <i>etc. on file</i>	
Distribution/	
Availability Code	
Dist	Avail and/or Spec
A-1	

DTIC
ELECTE
SEP 02 1987
S D



NASA Grant NGL 05-020-272
ONR Contract N00014-85-K-0111

DISTRIBUTION STATEMENT
Approved for public release
Distribution Unlimited

THE IMPACT OF VARVES ON SOLAR PHYSICS

R.N. Bracewell

Space, Telecommunications and Radioscience Laboratory, Stanford, CA 94305-4053

[Invited Talk to Solar Cycle Workshop, Stanford Sierra Lodge,

Fallen Leaf Lake, May 10-14, 1987]

Abstract. The discovery of 680-million year old varves by George Williams in South Australia, recording several millennia of fossil solar cycles, is a most exciting development that is bound to make an impact on solar physics. Already new problems of physical understanding have been posed by the the 315-year Elatina cycle and the separate 350-year cycle, or undulation, (Williams, 1985, 1986, Williams and Sonett, 1985).² The Elatina cycle evidences itself multiplicatively in the form of amplitude modulation with a distinctive nonsinusoidal envelope, while the undulation component is additive and quasisinusoidal (Bracewell and Williams, 1986). Both of these periodic phenomena are present in historical records of sunspots, but would not have been discerned from modern solar observations, which do not date back far enough. The explanation of two such sharply defined periods, in addition to the less sharply defined 22-year magnetic cycle, will require an understanding of solar physics that we do not yet have. Examples of the impact that the varve discovery is beginning to make are given, and a previously proposed mechanism for driving the activity cycle is extended in terms of a magnetic wave propagated radially outward from a deep torsional oscillator.

1. Stability of the Magnetic Cycle

The point of view provided by the varves has been a stimulus for some new discoveries of a physical kind. It has been accepted that the duration of the solar semicycle ranged from 8 to 17 years averaging 11.1 ± 1.55 years for the period 1611 to 1976; the ratio of the mean period T to the standard deviation ΔT was 7.2. This poor frequency stability suggested relaxation oscillations or damped resonances rather than quasi-monochromatic

circumstances. Now an additive undulation lengthens and shortens the interval from one sunspot minimum to the next in a calculable way and so the semicycle duration may be compensated. A simple way to do this is to work with the interval from one minimum to the next but one. We then see that the 22-year magnetic cycle has a standard deviation of only 2.1 years; thus the duration of the solar cycle is intrinsically much more stable than was thought (Bracewell, 1985, Bracewell and Williams, 1986). This conclusion, which is shown strikingly in Fig. 1, is in harmony with a statistical analysis by Dicke (1978) who argues against a random walk in the phase of the sunspot cycle.

- Fig. 1. Histograms for the duration of (a) sunspot semicycles, $\Delta T/T = 7.2$, (b) sunspot magnetic cycles, $\Delta T/T = 11.5$, (c) varve semicycles $\Delta T/T = 6.8$, (d) varve magnetic cycles $\Delta T/T = 11.6$ (from Bracewell and Williams, 1986).

2. The Third Harmonic

Harmonic analysis of the alternating sunspot number series $R_{\pm}(t)$ (Bracewell, 1953) has revealed that what appeared to be a third harmonic (Cole, 1973) of the 22-year fundamental is present also in the varves; but this perturbation is not really a harmonic at all, since it is not periodic. It is better understood as resulting from a three-halves nonlinear dependence of $R_{\pm}(t)$ on an inferred quasi-sinusoidal underlying influence $R_{lin}(t)$. The perturbation has the effect of sharpening the semicycle shape in accordance with a nonlinear relation

$$R \approx 100 |R_{lin}/83|^{3/2} \text{sgn}(R_{lin})$$

(Bracewell, 1987) introducing an inflexion into the crossover between one semicycle and the next. The nature of this effect is illustrated in Fig. 3, which adopts the idea (Bracewell, 1953) of treating the sunspot number in odd semicycles as negative. One period of a sinusoid is shown in the presence of a negative offset, such as existed around 1910 and produced sunspot maxima alternating between high and low (zig-zag effect). The second semicycle, which is both strengthened and lengthened, is sharpened by the nonlinearity, while the preceding semicycle is made blunt. Although the semicycle durations AB and BC have been rendered unequal, the duration AC of the magnetic cycle is not much changed from the period A'C' of the initial sinusoid.

- Fig. 2. The sunspot number $R_{\pm}(t)$ is derivable through a three halves power law from an underlying quasi-sinusoidal variation $R_{lin}(t)$.

The removal of artifacts due to nonlinearity will simplify subsequent physical interpretation. Sunspot area, which has been regarded as more significant than sunspot number, has been found to require a slightly stronger correction for nonlinearity.

- Fig. 3. A sinusoid (---) in the presence of negative offset (- - - - -) as affected by nonlinearity gives rise to the heavy curve, which exhibits inflexions at the zero crossing and is sharpened if strong.

3. Mechanisms for Solar Activity

It is a matter of vigorous discussion whether the surface manifestations of the solar cycle are underlain by zonal vortices (Bjerknes, 1926), toroidal fields (Babcock, 1961), azimuthal rolls (Ribes et al, 1985, Wilson, 1987a), or by some other cause (Wilson, 1987b). The prime mover for these fluid dynamic features is variously taken as the differential rotation, or convection, or is left underspecified, as with models invoking simultaneous initiation in opposite polar regions. Existing theories may also be categorized as to the phenomenon causing the observed quasi-periodicity. Yule's (1927) model was a resonator excited by random excitation; it failed, but largely because of the constraint forcing alternate extrema to be equal. It could be revived with reference to the alternating sunspot number concept R_{\pm} and in effect has been in Dicke's analysis of phase behavior. Babcock's model is in the category of a relaxation oscillator, where the period is set, not by a resonator, but by a relaxation process. The period of Wilson's convective rolls, whose power comes in part from dynamo action, is set by the time taken for the dynamo wave to reach the equator.

A different kind of scenario was introduced by Walén (1949) and later entertained by Richardson and Schwarzschild (1949), Menzel (1959), Dicke (1970), LaBonte (1986) and in my own papers. Only partial developments of the idea have been given; the common thread is that zonal magnetic fields originate at a level below the convective layer, rather than in it.

4. Two Correlations Requiring Explanation

A submerged central source is of particular interest to me because it seems to offer a way of explaining the correlation between phase and amplitude (Dicke, 1978). This correlation was strongly reconfirmed by Hilbert transform analysis (Bracewell, 1985) which yielded

$$\Delta\phi/2\pi = 0.0018E(t) + \text{const}$$

for the relation between instantaneous envelope $E(t)$ and instantaneous phase departure $\Delta\phi$.

The central source proposal also offers a possible Doppler shift mechanism (Bracewell, 1985) for a negative correlation discovered by Waldmeier (1935). In terms of the instantaneous envelope $E(t)$ we find

$$\Delta t = -0.043E(t) + \text{const}$$

for the variation Δt in cycle length. A reasonably good retrodiction of the sunspot number series can be constructed taking into account the connection between cycle length and envelope, and the two kinds of secular cycle known from the varves (Bracewell, 1986). Here is the tentative working model lying behind my view of the solar cycle.

5. Torsional Oscillator as Magnetic Wave Source

Deep in the sun, picture a flywheel whose center and axis coincide, perhaps only approximately, with the mass center and axis of angular momentum of the sun. The flywheel is like the pendulum of a clock and executes torsional vibrations whose period is set, at the stable amplitude of motion, by the rotational kinetic energy of the flywheel and by the potential energy of magnetic field lines stretched by the rotational motion. The dimensions of the flywheel are not known nor is the strength of the magnetic field, but the energy diverted from the nuclear energy source in the stirred core into rotational kinetic energy of the flywheel balances the damping by viscosity and wave radiation. In other words there is a clock comprising an energy source, a resonator, and a nonlinear damping mechanism that governs the amplitude. The physical conditions must be compatible with stable running of the clock since Precambrian times at the latest. The notion of a deep-seated chronometer comes from Dicke (1978).

Now imagine a wave, whose features are not yet known except that it possesses an azimuthal magnetic field with an equatorial nodal plane, being launched upward into the two hemispheres, the wave radiation to the north being in antiphase with that to the south. At intervals of 11 years, zonal magnetic fields arrive at the base of the convection zone where events leading to observable surface phenomena play themselves out, perhaps in much the same way as in other current working models.

Many questions can be asked about details of the wave source and the wave propagation that cannot at present be answered. Nevertheless it is customary to work with incomplete models of this type with a view to seeing how consistent they are with observed phenomena. The theory of continental drift is an example of an incomplete picture that was widely adopted as a working hypothesis even while basic details such as the mechanism that drives the drift, and the energy source, remained uncertain.

What observed effects does the magnetic wave picture have a bearing on? One is the semicycle shape, which can be accounted for rather simply by buoyancy forces (Parker 1979) accelerating the wave crests and troughs relative to the wave nodes (Bracewell, 1985, 1987). In Fig. 3 no provision was made for semicycle asymmetry. The wave model described here does however have the capacity to explain the early occurrence of sunspot maximum in strong semicycles as a consequence of magnetic buoyancy. Just as a sound wave is steepened on the leading slope because the denser crest travels faster, so magnetic buoyancy causes the early arrival of the wave antinodes relative to the nodes. It became possible to carry out the applicable buoyancy correction after the discovery of the three-halves law, present both in the varves and sunspot numbers, allowed this obscuring nonlinear effect to be removed. It was found that semicycle shapes could be matched simply in terms of maximum sunspot number as the controlling parameter (Bracewell, 1987). This is an attractive feature of a model with radial wave propagation from a deep torsional oscillator. It is not to be confused with an appeal to buoyancy made by Dicke (1978) in connection with the phase-amplitude correlation.

The observed correlation between amplitude and semicycle period noted by Waldmeier (1935) is attributable (Bracewell, 1985) to the Doppler effect of a time-varying ray-path length (the kind of frequency shift that arises with stationary sound source and detector in the presence of a convecting medium). Since the discovery of the varves, it has become necessary to allow for mechanisms capable of producing both the rather sinusoidal 350 year undulation and the more complex, double-humped 315 year Elatina cycle. A natural resonance of the wave propagation structure has been suggested for the 350-year period (Bracewell, 1985); the second could conceivably arise in the presumed flywheel, which in general might be expected to precess and nutate, perhaps under influences mediated by the tilt of the solar axis with respect to the ecliptic.

Phase stability of the clock might be quite high while at the same time the surface manifestation might wander in phase because of propagation effects. Temporary desynchronization of the two hemispheres is permitted by propagation inequalities from a central source, in an amount comparable with $\Delta\phi$. But any theory where the activity of each cycle originates in higher latitudes and progresses toward the equator should be asked to explain long term phase stability, while allowing short term desynchronization of the hemispheres.

Dicke (1978) presented analysis of the perturbation of 1761-1815 supporting the possibility of a coherent source despite phase perturbations at the surface, and my own analysis of instantaneous phase over the whole record (Bracewell, 1985) agrees. The magnetic cycle for varves has already been found to exhibit a more compact distribution of periods than the varve semicycle does, in agreement with the result mentioned above for sunspot number (Bracewell and Williams, 1986). When the Elatina cycle is fully taken into account, phase

analysis of the varves will place even tighter limits on the instability of the clock.

6. Conclusion

Clearly the magnetic wave idea is incomplete but contains some interesting possibilities and is compatible with the observations mentioned. It remains to sharpen up the difficulties this idea must overcome and to entertain it as a standard against which to compare the successes and difficulties of the convective roll and surface dynamo theories which we are also struggling to develop into comprehensive theories.

References

- Babcock, H.W. (1961), "The topology of the Sun's magnetic field and the 22-year cycle," *Astrophys. J.*, **133**, 572.
- Bjerknes, V. (1926), "Solar hydrodynamics," *Astrophys. J.*, **64**, 93.
- Bracewell, R.N. (1953), "The sunspot number series," *Nature*, **171**, 649.
- Bracewell, R.N. (1985), "The sunspot number series envelope and phase," *Aust. J. Phys.*, **38**, 1009.
- Bracewell, R.N. (1986), "Simulating the sunspot cycle," *Nature*, **323**, 516.
- Bracewell, R.N., (1987), "Three-halves law in sunspot cycle shape," (submitted for publication).
- Bracewell, R.N. & Williams, G.E. (1986), "Hilbert transform analysis of the Elatina varve record of solar activity," *Mon. Not. Roy. Astron. Soc.*, **223**, 457.
- Cole, T.W. (1973), "Periodicities in solar activity," *Solar Phys.*, **30**, 103.
- Dicke, R.H. (1970), "The rotation of the Sun," in *Stellar Rotation*, A. Slettebak ed., Reidel, Dordrecht-Holland.
- Dicke, R.H. (1978), "Is there a chronometer hidden deep in the Sun?" *Nature*, **276**, 676.
- LaBonte, B.J. (1986), reported in P.R. Wilson (1987b).
- Menzel, D.H. (1959), *Our Sun*, Harvard University Press, Cambridge, 1959.
- Parker, E.N. (1979), *Cosmical Magnetic Fields*, Clarendon Press, Oxford.
- Ribes, E., Mein, P., and Mangeney, A. (1985), "A large-scale meridional circulation in the convective zone," *Nature*, **318**, 170.
- Richardson, R.S. and Schwarzschild, M. (1949), *Proc. 11th Volta Conf.*, Rome 1953.
- Waldmeier, M. (1935), *Astronom. Mitteilungen Zürich*, **14**, no. 133, 105.
- Walén, C. (1949), referred to by T.G. Cowling in *The Sun*, T. Kuiper ed., Chicago University Press, 1953.
- Williams, G.E. (1985), "Solar affinity of sedimentary cycles in the late Precambrian Elatina formation," *Aust. J. Phys.*, **38**, 1027.
- Williams, G.E. (1981), "Sunspot periods in the late Precambrian glacial climate and solar planetary relations," *Nature*, **291**, 624.
- Williams, G.E. (1986), "The solar cycle in Precambrian time," *Sci. Amer.*, **254**, 88.
- Williams, G.E. and Sonett, C.P. (1985), "Solar signature in sedimentary cycles from the late Precambrian Elatina formation, Australia," *Nature*, **318**, 523.
- Wilson, P.R. (1987a), *Solar Phys.*, (in press).
- Wilson, P.R. (1987b), "Solar cycle workshop," *Solar Phys.*, (in press).
- Yule, G.U. (1926-1927), *Phil. Trans. Roy. Soc., A*, **226**, 267.

FIGURE CAPTIONS

Fig.1. Histograms for the duration of (a) sunspot semicycles, $\Delta T/T = 7.2$, (b) sunspot magnetic cycles, $\Delta T/T = 11.5$, (c) varve semicycles $\Delta T/T = 6.8$, (d) varve magnetic cycles $\Delta T/T = 11.6$ (from Bracewell and Williams, 1986).

Fig. 2. The sunspot number $R_{\pm}(t)$ is derivable through a three-halves power law from an underlying quasi-sinusoidal variation $R_{lin}(t)$.

Fig. 3. A sinusoid (—) in the presence of negative offset (- - - -) as affected by nonlinearity gives rise to the heavy curve, which exhibits inflexions at the zero crossing and is sharpened if strong.

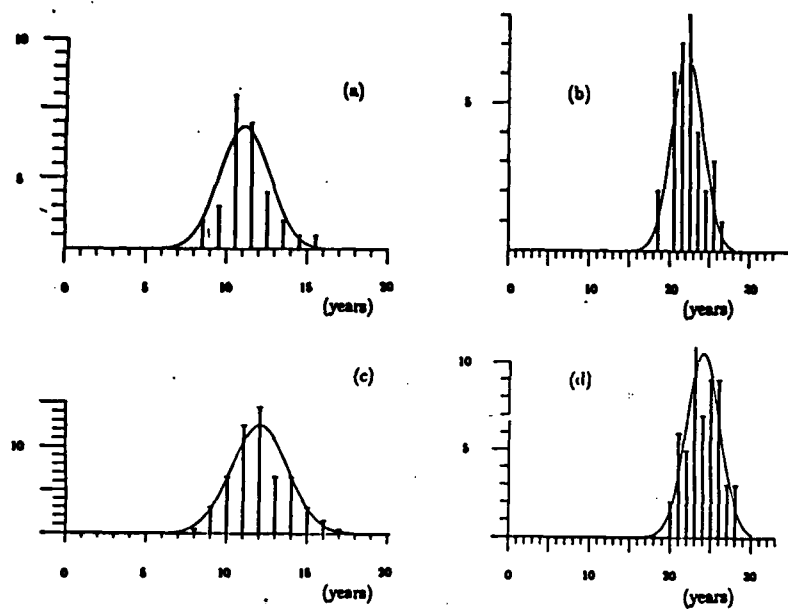


Fig. 1

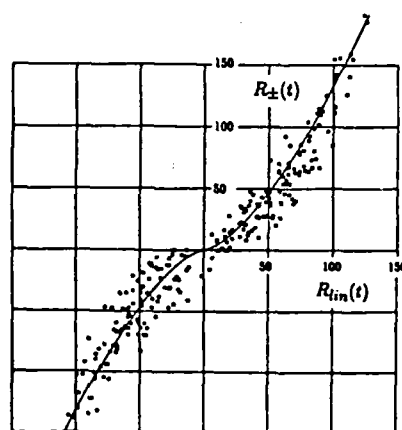


Fig. 2

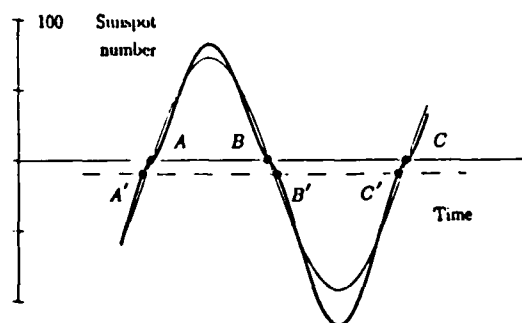


Fig. 3

END

9-87

DTIC